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August 27, 2015

Defense Technical Information Center
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Dear Sir/Madam:

Enclosed please find the package for the Interim Research Performance Report (for the last funding period) for the ONR project "Improving Aerosol and Visibility Forecasting Capabilities Using Current and Future Generations of Satellite Observations" with award number N00014-10-0816. Interim Research Performance Reports (annually) from previous years are also included. This package includes:

(1) Cover letter
(2) SF298 form (for the last funding period)
(3) Interim Research Performance Report (for the last funding period)
(4) SF298 forms and Interim Research Performance Reports for the fiscal years of 2011-2014

Please do not hesitate to let me know if you have any questions. My email is jzhang@atmos.und.edu, and my phone number is (701)-777-6342.

Sincerely Yours,

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
08/27/2015	Interim Research Performance Report	October 01 2014 -May 31, 2015

4. TITLE AND SUBTITLE
Improving Aerosol and Visibility Forecasting Capabilities Using Current and Future Generations of Satellite Observations

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-10-0816

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jianglong Zhang

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of North Dakota
Department of Atmospheric Sciences
4149 University Ave. Stop 9006
Grand Forks, ND 58202-9006

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
875 North Randolph Street
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release; distribution is Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The goal of this project is to improve the Navy's aerosol and visibility forecast capability through the development of advanced aerosol data assimilation schemes and construction of reliable data streams for operational aerosol data assimilation. Research findings from this 5-year project have been reported through more than 25 submitted/published authored and coauthored peer-reviewed journal papers and more than 30 conference presentations.

15. SUBJECT TERMS
Aerosol, data assimilation, satellite remote sensing, visibility forecast, electro-optical propagation

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Jianglong Zhang
U	U	U	UU	12	19b. TELEPHONE NUMBER *(Include area code)* (701)-777-6342

20150831113

Improving Aerosol and Visibility Forecasting Capabilities Using Current and Future Generations of Satellite Observations

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Award Number: N00014-10-0816

LONG-TERM GOALS

Advancing aerosol optical property studies from both observational and modeling perspectives is necessary for military applications, especially for operations with visibility-sensitive instruments such as electro-optical (EO) systems. The long-term goal of this study is to fully evaluate existing space-borne aerosol optical property data sets, innovatively construct new satellite aerosol retrieval schemes, and develop advanced methods for assimilating existing and new multi-sensor aerosol measurements for improving Navy's visibility and EO propagation forecasting capabilities.

OBJECTIVES (abstract from proposal)

Critical to both military and civilian applications, the Navy Aerosol Analysis and Prediction System (NAAPS) is the world's only truly operational global aerosol and visibility forecasting model. Recent studies indicate that the assimilation of satellite observations significantly improves NAAPS aerosol forecasting capability and reliability. To fully utilize the wide breadth and depth of various current satellite observations and prepare for future reductions in aerosol sensing satellites over the next decade, we propose to construct a multi-channel, multi-sensor, and multi-task assimilation system to improve NAAPS forecasts for both current and future applications. The specific objectives are to:

1. Finalize over-land and over-ocean aerosol assimilation methods using operational data assimilation (DA) quality Moderate Resolution Imaging Spectroradiometer (MODIS) and Multiangle Imaging SpectroRadiometer (MISR) aerosol products, and develop a framework for considering current and future satellite aerosol products.
2. Develop forward models to enable a radiance assimilation capability by: 1) improving forecast performance over cloudy regions using the Ozone Monitoring Instrument (OMI) Aerosol Index; and 2) preparing for the post-MODIS/MISR era using the Geostationary Operational Environmental Satellite (GOES).
3. Improve model representation of aerosol vertical profiles and the accuracy of aerosol speciation in NAAPS through the use of a 3-D aerosol assimilation method on satellite-based lidar observations and a generalized Angstrom exponent assimilation scheme.
4. Develop an improved 3-D parameterization for satellite observation and model forecasting error matrices using ground observations from the NASA Aerosol Robotic Network (AERONET) and the Micropulse Lidar Network (MPLNET).

APPROACH

To achieve the proposed objectives and long-term goals, research approaches of the project include constructing DA-grade satellite data for aerosol DA, developing new and advanced aerosol assimilation schemes, and advancing new and cutting-edge research to assist the proposed research topics.

Supported by this grant, Shi et al. (2011) suggested that large spatial discrepancies exist in operational satellite aerosol products such as MODIS and MISR. Thus, before applying satellite aerosol retrievals in aerosol analysis and forecasts, the uncertainties and biases in operational satellite aerosol products need to be fully evaluated. In the past few years of the project period, MODIS Deep Blue (DB) and MISR aerosol products have been studied, and schemes for constructing DA-grade MODIS DB and MISR aerosol products have been developed and transitioned to the Naval Research Laboratory (NRL). Continuing from FY14's effort, in FY15, the newly released Collection 6 MODIS Dark Target (DT) over water products have been evaluated for their potential applications in operational aerosol DA (Shi et al., 2014).

New improvements are also made in developing advanced aerosol DA schemes. In the past few years of the study period, a 3-D CALIOP DA scheme, which is coupled with 2D aerosol optical depth (AOD) assimilation using MODIS and MISR aerosol data, has been completed (Zhang et al. 2011; 2014) and transitioned to NRL. In FY14, a prototype GOES radiance assimilation system, specifically for aerosol analysis and forecasts, was designed and developed through coupling of the Community Radiative Transfer Model (CRTM) with NAAPS and NAVDAS. In FY15, attempts have been made to assimilate real GOES-13 data (e.g., Fig. 1).

Lastly, in FY15, exploratory studies have continued in research directions that could benefit the overall research goal of the project. A revised nighttime aerosol retrieval scheme (based on Johnson et al., 2013; developed with the support of this project) has been developed by using the variance in radiances within an artificial light source to retrieve AOD (McHardy et al., 2015). Research efforts have also continued to study the spatial and temporal distributions of above cloud aerosol events (Alfaro-Contreras et al., 2015), as well as complete the analysis of the effect of sub-surface bubbles on aerosol retrievals (Christensen et al., 2015), which has not been considered in aerosol retrievals prior to our study.

WORK COMPLETED

Overall research progress of the project

For the past few years, this project has focused on developing advanced aerosol DA schemes and constructing reliable data streams for operational aerosol DA. Data source-wise, DA-grade Moderate Resolution Imaging Spectroradiometer (MODIS) DeepBlue (DB) and Multiangle Imaging SpectroRadiometer (MISR) aerosol products have been developed. The enhanced southern ocean anomaly (ESOA), an anomaly found in the MODIS and MISR aerosol products, has been studied with respect to cloud contamination and subsurface oceanic bubbles. Methods have also been developed for cloud-clearing of MISR observations with MODIS data. DA scheme-wise, continuing from the PI's ONR YIP project, a 2-D/3-D aerosol assimilation package that assimilates both column-integrated aerosol optical depth (AOD) data and lidar vertical aerosol extinction profiles from Cloud-Aerosol

Lidar and Infrared Pathfinder Satellite Observations (CALIOP) has been completed and transitioned to NRL. A new prototype model for directly assimilating GOES radiance has also been developed. The regional and global impact of assimilating MODIS Dark Target (DT), MODIS DB, MISR and CALIOP aerosol products for aerosol analysis and forecasts has been evaluated. Beyond the proposed research topics, new and cutting-edge research efforts that directly relate to the proposed theme have been explored. In particular, innovative methods have been developed for retrieving nighttime AOD from Visible Infrared Imaging Radiometer Suite (VIIRS) observed artificial light sources. The spatial and temporal variations of above cloud aerosol events are evaluated and the impacts of above cloud aerosols to cloud property retrievals are studied. In addition, the relationship between surface particulate matter concentration and column integrated aerosol optical thickness has been investigated as functions of data quality and aerosol vertical distribution. Research findings from this project have been reported through a total of more than 25 submitted/published authored and coauthored peer-review journal papers and more than 30 conference presentations.

Research progress for the last reporting period (Oct. 1 2014 –May 30, 2015)

Continuing from FY14's effort, a revised version of our nighttime aerosol retrieval method has been developed. Currently, no reliable nighttime aerosol retrievals from passive-based sensors are available for operational aerosol forecasts (Zhang et al., 2011). While CALIOP has the capability of detecting nighttime aerosol vertical distribution, the profiling swath is limited. In FY13, a spatial contrast method was developed by deriving AOD through evaluating the radiance contrast between an artificial light source and nearby background pixels (Johnson et al., 2013). A revised method has also been attempted by retrieving nighttime aerosol optical thickness through measuring the variance in radiance within an artificial light source (McHardy et al., 2015). The revised method, which excludes the need for nearby pixels, has the potential to be applied to a much larger domain. Validated against nighttime High Spectral Resolution Lidar (HSRL) measurements and adjacent daytime AERONET data, the retrievals from the proposed methods are very promising (McHardy et al., 2015).

In FY14, a GOES radiance assimilation package was developed and tested with synthetic data. Implementation of the GOES radiance assimilation package with the use of real GOES-13 data was attempted in FY15. A total of 3 months of GOES-13 data from June-Aug. 2007 were processed and cloud screened. Collocated GOES-13 and AERONET data are used to evaluate the simulated GOES radiance from a GOES radiance simulator (a fully coupled NAAPS and CRTM system). The gridded GOES radiance data are further used for testing the GOES radiance assimilation system (Fig. 1).

In early 2014, Collection 6 Aqua MODIS aerosol products were released. We have evaluated over-water Collection 6 MODIS DT products with respect to cloud contamination, aerosol microphysical bias, and near surface wind conditions (Shi et al., 2014). The full evaluation of the DB and DT Aqua and Terra MODIS products will likely be a future study as the Collection 6 Terra MODIS products have been released one month (April 2015) prior to the end of the project.

Lastly, attempts have also been made to study the spatial and temporal variations in aerosol vertical distribution. While we are still working on converting the study to a peer-reviewed journal paper, the first phase of the study has been presented at the 2014 Fall AGU meeting (Toth et al. 2014).

RESULTS

An improved method for retrieving nighttime aerosol optical thickness from the VIIRS Day/Night Band (McHardy et al. 2015, submitted)

Using Visible/Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) data, a method, dubbed the "variance method" was developed for retrieving nighttime aerosol optical thickness (τ) values through the examination of the dispersion of radiance values above an artificial light source. Based on improvement to a previous algorithm, this updated method derives a semi-quantitative indicator of nighttime τ using artificial light sources. Nighttime τ retrievals from the newly-developed method are inter-compared with an interpolated value from late afternoon and early morning ground observations from four AErosol RObotic NETwork (AERONET) sites as well as column-integrated τ from one High Spectral Resolution Lidar (HSRL) site at Huntsville, AL during the NASA Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys ($SEAC^4RS$) campaign, providing diurnal coverage. Sensitivity studies were performed to examine the effects of lunar illumination on VIIRS τ retrievals made via the variance method, revealing that lunar contamination may have a smaller impact than previously thought. However. the small sample size of this study limits the conclusiveness thus far. VIIRS τ retrievals yield a coefficient of determination (r^2) of 0.60 and a root-mean-squared-error (RMSE) of 0.18 when compared against straddling daytime-averaged AERONET τ values. Preliminary results suggest that artificial light sources can be used for estimating regional and global nighttime aerosol distributions in the future.

Evaluating MODIS collection 6 dark target over water aerosol products for multi-sensor data fusion (Shi et al. 2014; presented at the 2014 AGU fall annual meeting)

MODIS aerosol products have been widely used in aerosol related climate, visibility, and air quality studies for more than a decade. Recently, the MODIS Collection 6 (C6) aerosol products from MODIS-Aqua have been released. The reported changes between C5 and C6 include updates to the retrieval algorithms and a new cloud-filtering process for over-ocean products. Thus it is necessary to fully evaluate the C6 products for applications that require high quality MODIS aerosol optical depth data, such as operational aerosol data assimilation. The uncertainties in the MODIS C6 DT over-ocean products are studied through both inter-comparing with MISR aerosol products and by evaluation against ground truth. Special attention is given to the low bias in MODIS DT products due to the misclassifications of heavy aerosol plumes as clouds. Finally, a quality-assured DA grade aerosol optical product is constructed for aerosol data assimilation related applications.

A Global and Regional Trend Study of the Vertical Distribution of Aerosols as Observed by CALIOP (Toth et al. 2014; presented at the 2014 AGU fall annual meeting)

Trends in atmospheric aerosol particle loading have gained increased attention in recent years due to their impact on Earth's radiation budget and global climate change. Past studies have examined this topic through aerosol optical depth (AOD) observations derived from passive satellite sensors such as MODIS and MISR. However, such passive sensors acquire only column-integrated measurements and thus can provide no insight into the vertical distribution of any AOD trends they might detect. Yet knowledge of aerosol vertical distribution and trends are critical for studies involving aerosol climate impacts and air quality. Using seven and a half years (June 2006 – December 2013) of aerosol profile data from Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), we investigate trends in

CALIOP-derived AOD at various altitudes throughout the atmospheric column. This differs from existing CALIOP-based climatological studies that focus solely on the mean state of aerosol vertical distribution. Daytime and nighttime analyses are decoupled to account for differences in the vertical structure of the troposphere, and detection sensitivity of CALIOP, between the two regimes. The results of this study are presented globally and for selected regions. Of particular interest are North Africa and Asia, as these are areas with frequently high AOD and have also exhibited trends from MODIS and MISR observations.

Progress with GOES radiance assimilation

In FY15, the prototype system for GOES radiance assimilation, which was built in FY14, has been tested with GOES-13 data. Figure 1a shows the gridded (1°x1° Latitude, Longitude) GOES radiance data from cloud free regions. Cloud-clearing of GOES data is performed based on the combination of visible/thermal IR threshold methods and a visible spatial variance test. Figure 1b shows the NAAPS aerosol optical depth fields without data assimilation and Fig. 1c shows the NAAPS AOD fields after radiance assimilation. A biomass-burning event in Central America, which is not found from the NAAPS natural run, is captured from the GOES radiance data assimilation. Still, this practice reveals potential problems in GOES radiance assimilation, which includes cloud and glint contamination of GOES data, as well as GOES visible channel signal degradation. These issues will be explored in a follow up ONR project.

IMPACT/APPLICATIONS

A new nighttime aerosol retrieval scheme has been developed with the use of the radiance variance within artificial light sources. The new scheme, which doesn't need a priori knowledge of aerosol properties or background information, has the potential to be implemented on a regional domain, and possibly a nighttime aerosol product for aerosol data assimilation.

TRANSITIONS

None.

RELATED PROJECTS

Ricardo Alfaro-Contreras is partially supported by a NSF EPSCoR grant. The CALIOP aerosol trend study is also supported by a NASA grant (NNX14AJ13G).

REFERENCES

Alfaro-Contreras, R., Zhang, J., Campbell, J. R., and Reid, J. S.: Investigating the frequency and trends in global above-cloud aerosol characteristics with CALIOP and OMI, Atmos. Chem. Phys. Discuss., 15, 4173-4217, doi:10.5194/acpd-15-4173-2015, 2015 [submitted, refereed].

Christensen, M., Zhang, J., Reid, J. S., Zhang, X., Hyer, E. J., and Smirnov, A.: A theoretical study of the effect of subsurface oceanic bubbles on the enhanced aerosol optical depth band over the southern oceans as detected from MODIS, Atmos. Meas. Tech., 8, 2149-2160, doi:10.5194/amt-8-2149-2015, 2015 [published, refereed].

Johnson R. S., J. Zhang, J. S. Reid, E. J. Hyer, and S. D. Miller, Toward Nighttime Aerosol Optical Depth Retrievals from the VIIRS Day/Night Band, Atmos. Meas. Tech., 6, 1245-1255, doi:10.5194/amt-6-1245-2013, 2013.

McHardy T., J. Zhang, J. S. Reid, S. D. Miller, E. J. Hyer, and R. Kuehn, An improved method for retrieving nighttime aerosol optical thickness from the VIIRS Day/Night Band, submitted to AMT, 2015.

Shi Y., J. Zhang, J. S. Reid, E. J. Hyer, McHardy T., L. Lee, Evaluating MODIS Collection 6 Dark Target Over Water Aerosol Products for Multi-sensor Data Fusion, Abstract A21F-3093, presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 16 Dec, 2014.

Shi Y., Zhang J., Reid J. S., Hyer E. J., Eck T. F., and Holben B. N., A critical examination of spatial biases between MODIS and MISR aerosol products – application for potential AERONET deployment, Atmos. Meas. Tech., 4, 2823–2836, 2011.

Toth T. D., J. Zhang, J. R. Campbell, J. S. Reid, M. Vaughan, A Global and Regional Trend Study of the Vertical Distribution of Aerosols As Observed By Caliop, Abstract A31D-3054, presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 17 Dec, 2014.

Zhang J., J.S. Reid, J.R. Campbell, E.J. Hyer, and D.L. Westphal, Evaluating the Impact of Multi-Sensor Data Assimilation on A Global Aerosol Particle Transport Model. J. Geophys. Res. Atmos., 119, 4674–4689, *doi:*10.1002/2013JD020975, 2014.

Zhang, J., J. R. Campbell, J. S. Reid, D. L. Westphal, N. L. Baker, W. F. Campbell, and E. J. Hyer, Evaluating the Impact of Assimilating CALIOP-derived Aerosol Extinction Profiles on a Global Mass Transport Model, , Geophys. Res. Lett., 38, L14801, doi:10.1029/2011GL047737, 2011 [published, refereed].

PUBLICATIONS (for the whole study period. Publications after Oct. 2014 are for this study period)

McHardy T., J. Zhang, J. S. Reid, S. D. Miller, E. J. Hyer, and R. Kuehn, An improved method for retrieving nighttime aerosol optical thickness from the VIIRS Day/Night Band, submitted to AMT, 2015 [submitted, refereed].

Alfaro-Contreras, R., Zhang, J., Campbell, J. R., and Reid, J. S.: Investigating the frequency and trends in global above-cloud aerosol characteristics with CALIOP and OMI, Atmos. Chem. Phys. Discuss., 15, 4173-4217, doi:10.5194/acpd-15-4173-2015, 2015 [submitted, refereed].

Reid, J. S., co-authors, and *J. Zhang*, Observations of the temporal variability in aerosol properties and their relationships to meteorology in the summer monsoonal South China Sea/East Sea: the role of monsoonal flows, the Madden–Julian Oscillation, tropical cyclones, squall lines and cold pools, *Atmos. Chem. Phys.*, Atmos. Chem. Phys., 15, 1745-1768, doi:10.5194/acp-15-1745-2015, 2015 [published, refereed].

Christensen, M., Zhang, J., Reid, J. S., Zhang, X., Hyer, E. J., and Smirnov, A.: A theoretical study of the effect of subsurface oceanic bubbles on the enhanced aerosol optical depth band over the southern oceans as detected from MODIS, Atmos. Meas. Tech., 8, 2149-2160, doi:10.5194/amt-8-2149-2015, 2015 [published, refereed].

Long M.S., W.C. Keene, B. Reichl, T. Hara, *J. Zhang, Y. Shi*, D.J. Erickson, J.S. Reid, B. Fox-Kemper, T. Craig, I. Ginis, Evaluation of Maine aerosol production simulated using the WaveWatchIII prognostic Wave Model coupled to the Community Atmospheric Model within the Community Earth System Model, submitted to JGR, 2015 [submitted, refereed].

Rubin J. I., J.S. Reid, J. A. Hansen, J. L. Anderson, N. Collins, T. J. Hoar, T. Hogan, P. Lynch, J. McLay, C. Reynolds, W. Sessions, D. L. Westphal, and *J. Zhang*, Development of the Ensuble Navy Aerosol Analysis Prediction System (ENAAPS) and its application of the Data Assimilation

Research Testbed (DART) in support of aerosol forecasting, submitted to ACP, 2015 [submitted, refereed].

Lynch P. J.S. Reid, D. L. Westphal, *J. Zhang*, T. Hogan, E. J. Hyer,. C. Curtis, D. A. Hegg, J. R. Campbell, J. Rubin, W. Session, *Y. Shi*, F. J. Turk, and A. Walker, Development studies towards an 11-year global gridded aerosol optical thickness reanalysis for climate and applied applications, submitted to ACP, 2015 [submitted, refereed].

Kaku K., J. S. Reid, E. Reid, K. Ross-Langerman, S. Piketh, S. Cliff, A. Al Mandoos, S. Broccardo, Y. Zhao, and *J. Zhang*, Investigation of the relative fine and coarse mode aerosol loadings and properties in the Southern Arabian Gulf Region, submitted to Atmospheric Research, 2015 [submitted, refereed].

Zhang J., J.S. Reid, J.R. Campbell, E.J. Hyer, and D.L. Westphal, Evaluating the Impact of Multi-Sensor Data Assimilation on A Global Aerosol Particle Transport Model. J. Geophys. Res. Atmos., 119, 4674–4689, *doi:*10.1002/2013JD020975, 2014 [published, refereed].

Alfaro-Contreras R., Zhang J., R. J.R. Campbell, R.E. Holz, and J.S. Reid, Evaluating the Impact of Aerosol Particles above Cloud on Cloud Optical Depth Retrievals from MODIS, J. Geophys. Res. Atmos., 119, 5410–5423, *doi:*10.1002/2013JD021270, 2014 [published, refereed].

Shi Y., Zhang J., J.S. Reid, B. Liu, E.J. Hyer, Critical evaluation of cloud contamination in the MISR aerosol products using MODIS cloud masking products, Atmos. Meas. Tech., 7, 1791-1801, doi:10.5194/amt-7-1791-2014, 2014 [published, refereed].

Toth, T.D., J. Zhang, J.R. Campbell, E.J. Hyer, J.S. Reid, Y. Shi, and D. L. Westphal, Impact of Data Quality and Surface-to-Column Representativeness on the PM2.5/Satellite AOD Relationship for the Continental United States, Atmos. Chem. Phys., 14, 6049-6062, doi:10.5194/acp-14-6049-2014, 2014 [published, refereed].

Johnson R. S., J. Zhang, J. S. Reid, E. J. Hyer, and S. D. Miller, Toward Nighttime Aerosol Optical Depth Retrievals from the VIIRS Day/Night Band, Atmos. Meas. Tech., 6, 1245-1255, doi:10.5194/amt-6-1245-2013, 2013 [published, refereed].

Shi Y., J. Zhang, J. S. Reid, E. Hyer, and N. C. Hsu, Critical evaluation of the MODIS Deep Blue aerosol optical depth product for data assimilation over North Africa, Atmos. Meas. Tech., 6, 949-969, doi:10.5194/amt-6-949-2013, 2013 [published, refereed].

Toth T. D., J. Zhang, J. R. Campbell, J. S. Reid, Y. Shi, R. S. Johnson, A. Smirnov, M. A. Vaughan and D. M. Winker, Investigating Elevated Aqua MODIS Aerosol Optical Depth Retrievals over the Mid-Latitude Southern Oceans through Intercomparison with Co-Located CALIOP, MAN, and AERONET Datasets, J. Geophys. Res, Atmos., 118, doi:10.1002/jgrd.50311, 2013 [published, refereed].

Reid J., E. J. Hyer, *R. Johnson*, B. N. Holben, *J. Zhang*, J. R. Campbell, S. A. Christopher, L. Di Girolamo, L. Giglio, R. E. Holz, C. Kearney, J. Miettinen, E. A. Reid, F. J. Turk, J. Wang, P. Xian, R. J. Yokelson, G. Zhao, R. Balasubramanian, B. N. Chew, S. Janai[1], N. Lagrosas, P. Lestari, N. Lin, M. Mahmud, B. Norris, A. X. Nguyen, N. T. K. Oahn, M. Oo, S. Salinas, and S. C. Liew, Observing the Southeast Asian aerosol system by remote sensing: A critical review for the Seven Southeast Asian Studies (7SEAS) program, *Atmospheric Research*, 122 (2013), pp. 403–468, doi:10.1016/j.atmosres.2012.06.005, 2013 [published, refereed].

Campbell J.R., J. S. Reid, D. L. Westphal, *J. Zhang*, B. N. Chew, E. J. Welton, A. Shimizu and N. Sugimoto, Characterizing aerosol particle composition and the vertical profile of extinction and linear depolarization over Southeast Asia and the Maritime Continent: the 2007-2009 view from CALIOP, *Atmospheric Research*, 122, pp. 520–543, doi:10.1016/j.atmosres.2012.05.007, 2013 [published, refereed].

Meskhidze, N., Petters, M. D., Tsigaridis, K., Bates, T., O'Dowd, C., Reid, J., Lewis, E. R., Gantt, B., Anguelova, M. D., Bhave, P. V., Bird, J., Callaghan, A. H., Ceburnis, D., Chang, R., Clarke, A., de

Leeuw, G., Deane, G., DeMott, P. J., Elliot, S., Facchini, M. C., Fairall, C. W., Hawkins, L., Hu, Y., Hudson, J. G., Johnson, M. S., Kaku, K. C., Keene, W. C., Kieber, D. J., Long, M. S., Mårtensson, M., Modini, R. L., Osburn, C. L., Prather, K. A., Pszenny, A., Rinaldi, M., Russell, L. M., Salter, M., Sayer, A. M., Smirnov, A., Suda, S. R., *Toth, T. D.*, Worsnop, D. R., Wozniak, A. and Zorn, S. R. (2013), Production mechanisms, number concentration, size distribution, chemical composition, and optical properties of sea spray aerosols. Atmosph. Sci. Lett.. doi: 10.1002/asl2.441 [published, refereed].

Xian, P., J.S. Reid, S.A. Atwood, *R.S. Johnson*, E.J. Hyer, D.L. Westphal, W. Sessions, Smoke aerosol transport patterns over the maritime continent, Atmos. Res., Volume 122, Pages 469–485, March, 2013 [published, refereed].

Sayer, A. M., N. C. Hsu, C. Bettenhausen, Z. Ahmad, B. N. Holben, A. Smirnov, G. E. Thomas, and *J. Zhang* , SeaWiFS Ocean Aerosol Retrieval (SOAR): Algorithm, validation, and comparison with other data sets, J. Geophys. Res., 117, D03206, doi:10.1029/2011JD016599, 2012 [published, refereed].

Yu, H., Zhang. Y., Chin M., Liu Z., Omar A., Remer L. A. Yang Y., Yuan T. and *Zhang J.* An Intergrated Analysis of Aerosol above Clouds from A-Train Multi-sensor Measurements, 121, 125–131, 2012 [published, refereed].

Campbell J.R., J. L. Tackett, J. S. Reid, *J. Zhang*, C. A. Curtis, E. J. Hyer, W. R. Sessions, D. L.Westphal, J. M. Prospero, E. J. Welton, A. H. Omar, M. A. Vaughan, and D. M.Winker, Evaluating nighttime CALIOP 0.532μm aerosol optical depth and extinction coefficient retrievals, Atmos. Meas. Tech., 5, 2143–2160, doi:10.5194/amt-5-2143-2012, 2012 [published, refereed].

Sayer, A. M., Hsu, N. C., Bettenhausen, C., Jeong, M.-J., Holben, B. N., and *Zhang, J.*: Global and regional evaluation of over-land spectral aerosol optical depth retrievals from SeaWiFS, Atmos. Meas. Tech. Discuss., 5, 2169-2220, doi:10.5194/amtd-5-2169-2012, 2012 [published, refereed].

Zhang, J., J. R. Campbell, J. S. Reid, D. L. Westphal, N. L. Baker, W. F. Campbell, and E. J. Hyer, Evaluating the Impact of Assimilating CALIOP-derived Aerosol Extinction Profiles on a Global Mass Transport Model, , Geophys. Res. Lett., 38, L14801, doi:10.1029/2011GL047737, 2011 [published, refereed].

Zhang, J. and Reid, J. S.: A decadal regional and global trend analysis of the aerosol optical depth using a data-assimilation grade over-water MODIS and Level 2 MISR aerosol products, Atmos. Chem. Phys. Discuss., 10, 18879-18917, doi:10.5194/acpd-10-18879-2010, Nov. 2010 [published, refereed].

Shi Y., Zhang J., Reid J. S., Hyer E. J., Eck T. F., and Holben B. N., A critical examination of spatial biases between MODIS and MISR aerosol products – application for potential AERONET deployment, Atmos. Meas. Tech., 4, 2823–2836, 2011 [published, refereed].

Shi, Y., J. Zhang, J. S. Reid, B. N. Holben, E. J. Hyer, and C. Curtis.: An analysis of the collection 5 MODIS over-ocean aerosol optical depth product for its implication in aerosol assimilation, Atmos. Chem. Phys., 11, 557-565, doi:10.5194/acp-11-557-2011, 2011 [published, refereed].

Hyer, E. J., J. S. Reid, and *J. Zhang*, An over-land aerosol optical depth data set for data assimilation by filtering, correction, and aggregation of MODIS Collection 5 optical depth retrievals, Atmos. Meas. Tech., 4, 379-408, doi:10.5194/amt-4-379-2011, 2011 [published, refereed].

Smirnov, A., B. N. Holben, D. M. Giles, I. Slutsker, N. T. O'Neill, T. F. Eck, A. Macke, P. Croot, Y. Courcoux, S. M. Sakerin, T. J., Smyth, T. Zielinski, G. Zibordi, J. I. Goes, M. J. Harvey, P. K. Quinn, N. B. Nelson, V. F. Radionov, C. M. Duarte, R. Losno, J. Sciare, K. J. Voss, S. Kinne, N. R. Nalli, E. Joseph, K. Krishna Moorthy, D. S. Covert, S. K. Gulev, G. Milinevsky, P. Larouche, S. Belanger, E. Horne, M. Chin, L. A. Remer, R. A. Kahn, J. S. Reid, M. Schulz, C. L. Heald, *J. Zhang*, K. Lapina, R. G. Kleidman, J. Griesfeller, B. J. Gaitley, Q. Tan, and T. L. Diehl, Maritime Aerosol Network as a component of AERONET – first results and comparison with global aerosol

models and satellite retrievals, Atmos. Meas. Tech. Discuss., 4, 1-32, doi:10.5194/amtd-4-1-2011, 2011 [published, refereed].

Patadia F., S. A Christopher, *J. Zhang*, Development of Empirical Angular Distribution Models for Smoke Aerosols - Part 1. Methods, *J. Geophys. Res.*, D14203, doi:10.1029/2010JD015033, 2011 [published, refereed].

Zhang J., M. Christensen, T. D. Toth, J. S. Reid, E. J. Hyer, J. R. Campbell, and X. Zhang, An investigation of the Enhanced Southern Oceans Anomaly (ESOA) over high latitude oceans, Joint between the 19th Conference on Air-Sea Interaction; the 17th Conference on Atmospheric Chemistry; and the Seventh Symposium on Aerosol-Cloud-Climate Interactions, Phoenix, AZ, Jan. 6, 2015.

Toth T., J. Zhang, J. R. Campbell, J. S. Reid, and M. A. Vaughan, A Trend Analysis of Global and Regional CALIOP-Based Aerosol Vertical Distribution, 14th Annual Student Conference, Phoenix, AZ, Jan. 4, 2015.

Rubin J., J. S. Reid, J. Hansen, J. Anderson, J. Campbell, N. Collins, T. Hoar, and *J. Zhang*, An Examination of Satellite Aerosol Product Assimilation in an Aerosol Transport Model Using Ensemble Versus Variational Methods, Abstract A21F-3101, presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 16 Dec, 2014.

Campbell J., R. Alfaro-Contreras, V. Buchard, *T. D. Toth*, M. Vaughan, *J. Zhang*, The Impact of Caliop Aerosol Profiling: How *Z* Influences the *X, Y S*atellite Perspective, Abstract A24B-02, presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 16 Dec, 2014.

Alfaro-Contreras R., J. Zhang, J. S. Reid, J. R. Campbell, Inter-comparison of Above-Cloud Aerosol Observation from OMI and CALIOP, Abstract A12A-08, presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 15 Dec, 2014.

McHardy T., J. Zhang, J. S. Reid, E. J. Hyer, Investigating Methods for Nighttime Aerosol Optical Depth Retrieval Using the VIIRS Day/Night Band, Abstract A51B-3027, presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 19 Dec, 2014.

Toth T. D., J. Zhang, J. R. Campbell, J. S. Reid, M. Vaughan, A Global and Regional Trend Study of the Vertical Distribution of Aerosols As Observed By Caliop, Abstract A31D-3054, presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 17 Dec, 2014.

Shi Y., J. Zhang, J. S. Reid, E. J. Hyer, McHardy T., L. Lee, Evaluating MODIS Collection 6 Dark Target Over Water Aerosol Products for Multi-sensor Data Fusion, Abstract A21F-3093, presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 16 Dec, 2014.

Christensen M., J. Zhang, J. S. Reid, E. J. Hyer, The Impacts of Oceanic Bubbles on the Elevated Southern Oceans Anomaly (ESOA) Over High Latitude Oceans, Abstract A21E-3082, presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 16 Dec, 2014.

T.D. Toth, J. Zhang, J.R. Campbell, J.S. Reid, and M.A. Vaughan, Global and Regional Trends of Aerosol Vertical Distribution As Observed By CALIOP: Preliminary Findings, CALIPSO/CloudSat Science Team Meeting, Alexandria, VA, 2014.

Zhang J., J. S. Reid, J. R. Campbell, E. J. Hyer, *Y. Shi, and R. Alfaro-Contreras*, Investigating the Impact of Cloud and Aerosol Contamination in Satellite Products used for Climate Forcing Studies, Six Symposium on Aerosol-Cloud-Climate Interactions, Atlanta, GA, Feb. 5, 2014.

Travis D. Toth, J. Zhang, J. R. Campbell, E. J. Hyer, J. S. Reid, *Y. Shi*, and D. L. Westphal, An Evaluation of Utilizing Passive and Active Satellite Aerosol Products as Proxies for Surface-Based PM2.5 Concentrations, 13th Annual Student Conference, Atlanta, GA, Feb. 2, 2014.

Zhang J. R. S. Johnson, E. J. Hyer, S. Miller, and J.S. Reid, Preliminary study of nighttime aerosol optical depth retrieval using the VIIRS DNB, 2013 EUMETSAT satellite conference, Vienna, 2013.

Reid J.S., E.H. Hyer, *J. Zhang*, T.F. Eck, J. Wang, Signal, scale, and context: Making sense of high resolution AOT data, Abstract A24C-02, presented at 2012 Fall Meeting, AGU, San Francisco, Calif., 9-13 Dec, 2013.

Reid J.S., B.N. Holben, *J. Zhang*, J.R. Campbell, E. Edgerton, J.A. D. Gouw, E.W. Eloranta, J.L. Hand, R. Holz, E.J. Hyer, D.J. Jacob, K. Kaku; S. kuang, P. Lynch, M. Newchurch, B.A. Schichtel, S. L. Shaw, Y. Shi, O.B. Toon, and C.R. Trepte, Aerosol Optical Thickness Patterns and their Trend in the Southeastern United States, Abstract A31I-06, presented at 2013 Fall Meeting, AGU, San Francisco, Calif., 9-13 Dec, 2013.

Toth T.D., J. Zhang, J.S. Reid, D.L. Westphal, J.R. Campbell, E.J. Hyer, and *Y. Shi*, Impact of Data Quality and Surface-to-Column Representativeness on the PM2.5/Satellite AOD Relationship for the Continental United States, Abstract A43D-0304, presented at 2013 Fall Meeting, AGU, San Francisco, Calif., 9-13 Dec, 2013.

Alfaro-Contreras R., J. Zhang, J.S. Reid, J.R. Campbell, Evaluating the Impact of Smoke Particle Absorption on Passive Satellite Cloud Optical Depth Retrievals, Abstract A51A-0004, presented at 2013 Fall Meeting, AGU, San Francisco, Calif., 9-13 Dec, 2013.

Lynch P., J.S. Reid, *J. Zhang*, D.L. Westphal, J.R. Campbell, C.A. Curtis, D. Hegg, E.J. Hyer; W. Sessions, Y. Shi, and J. Turk, Abstract A53K-03, presented at 2013 Fall Meeting, AGU, San Francisco, Calif., 9-13 Dec, 2013.

Hyer, E., *J. Zhang*, J.S. Reid, W. R. Sessions, C. A. Curtis, and D. L. Westphal, Operational Assimilation of Aerosol Optical Depth from NPP VIIRS in a Global Aerosol Model, Ninth Annual Symposium on Future Operational Environmental Satellite Systems, TJ18.2A, Austin, TX, January, 2013.

Zhang J., J. S. Reid, J. R. Campbell, E. J. Hyer, R. S. Johnson, *Y. Shi*, and D. L. Westphal, Sensitivity of Aerosol Climate Forcing to the Existing Satellite Observations, Fifth Symposium on Aerosol-Cloud-Climate Interactions, Austin, TX, January, 2013.

Shi Y., J. Zhang, J. S. Reid, B. Liu, R. Deshmukh, Critical evaluation of cloud contamination in MISR aerosol product using collocated MODIS aerosol and cloud products, Abstract A13J-0310, presented at 2012 Fall Meeting, AGU, San Francisco, Calif., 3-7 Dec, 2012.

Johnson S. R., J. Zhang, J. S. Reid, E. J. Hyer, S. D. Miller, Impact of VIIRS on Multi-Sensor Aerosol Optical Depth Data Assimilation, Abstract A13J-0318, presented at 2012 Fall Meeting, AGU, San Francisco, Calif., 3-7 Dec, 2012.

Hyer J. E., J. S. Reid, *J. Zhang*, C. A. Curtis, W. R. Sessions, D. L. Westphal, Satellite aerosol observations for air quality: matching the scales of observations and applications, Abstract A11L-01, , presented at 2012 Fall Meeting, AGU, San Francisco, Calif., 3-7 Dec, 2012.

T.D. Toth, J. Zhang, J.R. Campbell, J.S. Reid, *Yingxi Shi, R.S. Johnson*, Alexander Smirnov, and M.A. Vaughan, An Intercomparison of MODIS, CALIOP, and MAN to Investigate Elevated Passive Satellite Marine Aerosol Optical Depth Retrievals over the Mid-Latitude Southern Oceans, Sea Spray Aerosol Workshop, Raleigh, NC, June, 2012.

Zhang J., J. S. Reid, J. R. Campbell, E. J. Hyer, D. L. Westphal, *Y. Shi, R. S. Johnson*, and N. L. Baker, Development of a Multi-Sensor Aerosol Data Assimilation Method From MODIS, MISR, and CALIPSO Aerosol Products for Operational and Climate Applications, 18th Conference on Satellite Meteorology, Oceanography and Climatology/ First Joint AMS-Asia Satellite Meteorology Conference, New Orleans, 22-26, January, 2012.

James R. Campbell, *Jianglong Zhang*, Jeffrey S. Reid, Douglas L. Westphal, Walter R. Sessions, Angela Benedetti, Ellsworth J. Welton, Aerosol Lidar Profiling and Data Assimilation for Operational Global Mass transport Modeling and Visibility Forecasting, 26th International *L*aser Radar Conference, Porto Heli, Greece, June, 2012.

Westphal, D. L., R. B. Husar, S. E. McClure, J. R. Campbell, E. J. Hyer, J. S. Reid, W. R. Sessions, W. Eberhard and *J. Zhang*, Analyses and Forecasts of LRT of Particulates to the North America, *AAAR Annual Conference*, 2012.

Reid J., R. S. Johnson, E. Hyer, *J. Zhang*, J. R. Campbell, S. A. Christopher, L. Di Girolamo, L. Giglio, J. P. Hoffman, B. Holben, R. Holz, A. P. Kuciauskas, S. C. Liew, J. Miettinen, F. J. Turk, J. Wang, E. J. Welton, and P. Xian, Observing and Understanding the Southeast Asian Aerosol Environment: A Survey of Remote Sensing Tools for the 7 Southeast Asian Studies (7SEAS) Program (invited), 18th Conference on Satellite Meteorology, Oceanography and Climatology/ First Joint AMS-Asia Satellite Meteorology Conference, New Orleans, 22-26, January, 2012.

Toth T. D., Y. Shi, J. Zhang, J. R. Campbell, and J. S. Reid, A Satellite Analysis of Aerosol and Cloud Properties Over the Southern Midlatitude Oceans, Fourth Symposium on Aerosol-Cloud-Climate Interactions, New Orleans, 22-26, January, 2012.

Johnson R. S., J. Zhang, J. S. Reid, E. J. Hyer, J. R. Campbell, D. L. Westphal, W. Sessions, The impact of multi-sensor satellite aerosol products on aerosol data assimilation in the NAAPS model, Abstract A53C-0357 presented at 2011 Fall Meeting, AGU, San Francisco, Calif., 5-9 Dec, 2011.

Shi, Y., J. Zhang, J. S. Reid, B. Liu, R. Deshmukh, Multi-sensor Analysis on Data-Assimilation-Quality MISR Aerosol Products, Abstract A53C-0358 presented at 2011 Fall Meeting, AGU, San Francisco, Calif., 5-9 Dec, 2011.

T. D. Toth, Y. Shi, J. Zhang, J. R. Campbell, J. S. Reid, A Multi-Sensor Analysis of Satellite Aerosol Optical Depth Retrievals Over the Southern Oceans, Abstract A53C-0363 presented at 2011 Fall Meeting, AGU, San Francisco, Calif., 5-9 Dec, 2011.

Reid, J. S., J. R. Campbell, L. Di Girolamo, D. Hegg, E. J. Hyer, W. C. Keene, A. Smirnov, T. D. Toth, A. van Eijk; *J. Zhang*, A Critical Examination of Aerosol Observability in the Clean Marine Environment *(Invited),* Abstract A24A-01 presented at 2011 Fall Meeting, AGU, San Francisco, Calif., 5-9 Dec, 2011.

Campbell, J. R., J. L. Tackett, J. S. Reid, *J. Zhang*, D. L. Westphal, M. Vaughan, D. M. Winker, E. J. Welton, J. M. Prospero, A. Shimizu, N. Sugimoto, Evaluating CALIOP Nighttime Level 2 Aerosol Profile Retrievals Using a Global Transport Model Equipped with Two-Dimensional Variational Data Assimilation and Ground-Based Lidar Measurements, Abstract A52D-04, presented at 2011 Fall Meeting, AGU, San Francisco, Calif., 5-9 Dec, 2011.

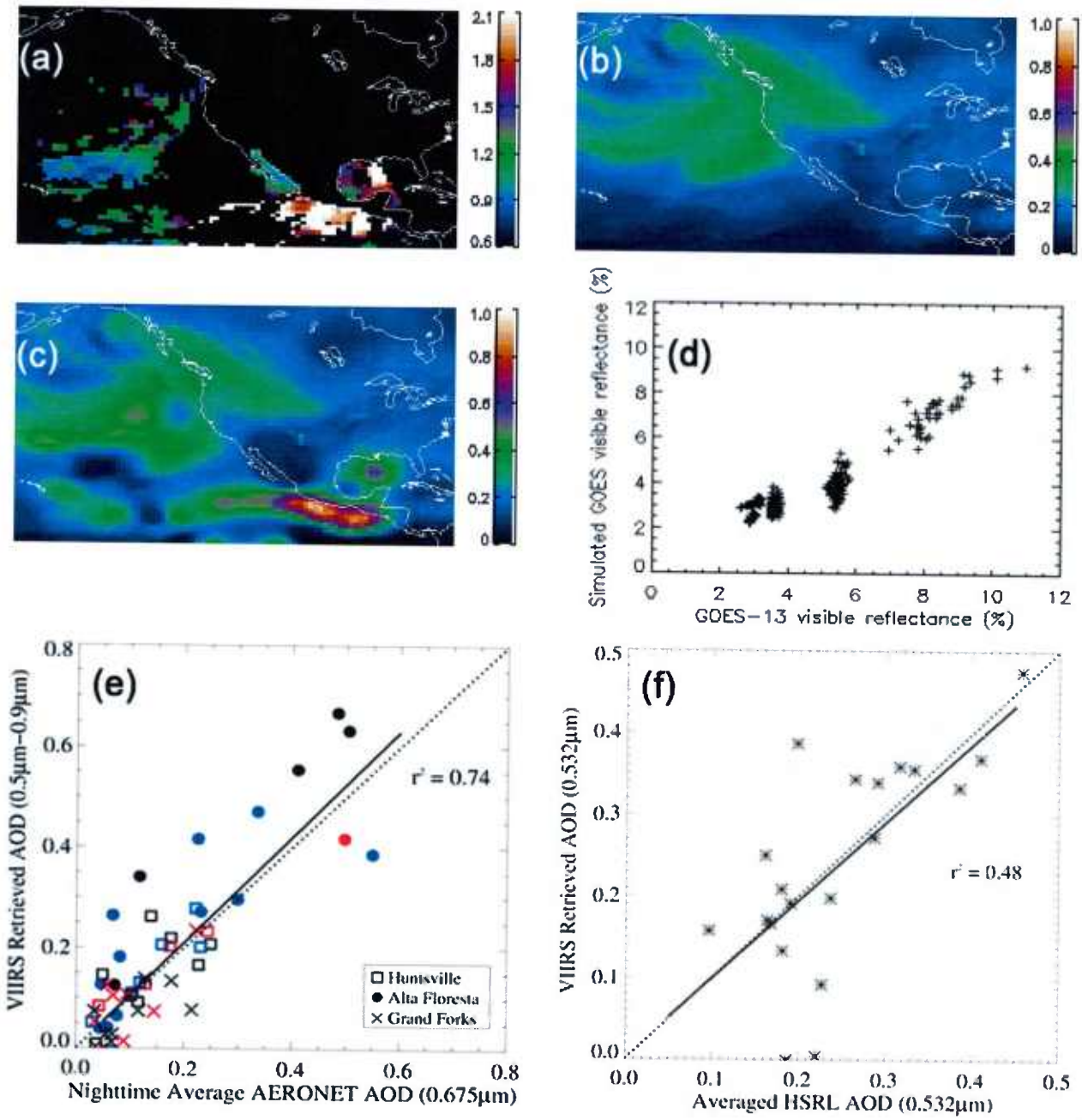

Figure 1. a). Gridded GOES-13 visible radiance (mW/m^2-sr-cm^{-1}) over cloud free regions for 18UTC, May 15, 2007. b) AOD (0.55 μm) distributions from NAAPS natural run for 18UTC, May 15, 2007. c). NAAPS analysis with GOES radiance assimilation using data from Figure 1a (AODs at the 0.55 μm spectral channel). d) Simulated (using the NAAPS-CRTM system) versus measured over water GOES-13 reflectance using a collocated GOES, NAAPS and AERONET dataset for the period of June 1 –Aug. 31, 2015. AERONET AOD values and NAAPS aerosol vertical distributions are used in the simulations. e) VIIRS retrieved nighttime AOD for a new method developed in this study period as a function of straddling daytime-averaged AERONET AOD for Huntsville (square), Alta Floresta (circle) and Grand Forks ("x"). One-to-one (dotted) and best-fit (solid) lines are also shown. f) VIIRS retrieved AOD as a function of Wisconsin HSRL retrieved total-column AOD for Huntsville, Alabama.